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Investment-cast Titanium and Aluminum Alloys save Material/labor/time/cost compared to Wrought Material; Navy Goal -- Improved Quality Investment - Cast Ti-6A1-4V parts for the V-22 program; Fatigue-Critical Airframe Parts: Fatigue initiation dominates lifetime; Problem Areas of Castings: Residual porosity, inclusions, and effective grain size; Fatigue Initiation; Microstructure; Defect data required to optimize casting and HIPing parameters.

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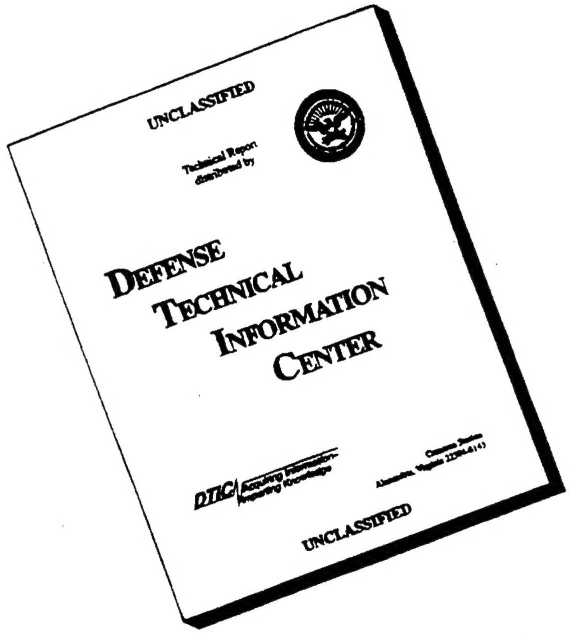

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FATIGUE INITIATION STUDY OF INVESTMENT CAST TI-6AL-4V ALLOY

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CLEARED FOR
OPEN PUBLICATION

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BACKGROUND

- Investment-cast Titanium and Aluminum Alloys save Material/Labor/Time//Cost Compared to Wrought Material.
- <u>Navy Goal</u> - Improved Quality Investment-Cast Ti-6Al-4V parts for V-22 program.
- Fatigue-Critical Airframe Parts: Fatigue Initiation Dominates Lifetime.
- Problem Areas of Castings: Residual porosity, Inclusions, and Effective Grain Size.
- Fatigue Initiation↔Microstructure↔Defect Data Required to Optimize Casting and HIPping Parameters.

THEORY: TI-6AL-4V

- Phase transformation: Solution temp. = 1825°C
  β-phase (BCC crystal structure) ↔ α-phase (HCP crystal structure)

- Investment casting cooled from melt to RT in ceramic mold.

- Hot-isostatic-pressing (HIPping) of casting performed at elevated temperature to eliminate porosity.

- β-solution treatment performed under vacuum to produce Widmanstatten (colony) microstructure - <u>Gives superior fracture toughness, fatigue, and creep properties</u>.

- Colonies: Packets of similarly-oriented, alternating α- and β-plates

THEORY-FATIGUE INITIATION

- Fatigue crack initiation associated with heterogeneous slip on basal and/or prismatic slip planes.
- Extrusions/intrusions generated at surface during cycling observed to nucleate microcracks.
- Shear stress component governs initiation due to slip.
- α-plate colony and prior-β grain boundaries have been associated with initiation and/or arrest of microcracks.
- <u>General Rule</u>: Initiation lifetime decreases and propagation lifetime increases with increasing mean colony size.

EXPERIMENTAL PROCEDURE

- Cylindrical, Hourglass-Shaped Specimens Machined From Large Investment Casting of Ti-6Al-4V (Gage Length Polished to 0.3 Micron Al_2O_3 Finish).

- High-Cycle-Fatigue Testing Performed Under Stress Control on MTS Servohydraulic Mechanical Test Machine.

- Test Conditions: Steady Stress = 40 ksi
Frequency = 20 Hz
Waveform = Sinusoidal
Stress amplitude range = 30-50 ksi

EXPERIMENTAL MEASUREMENTS

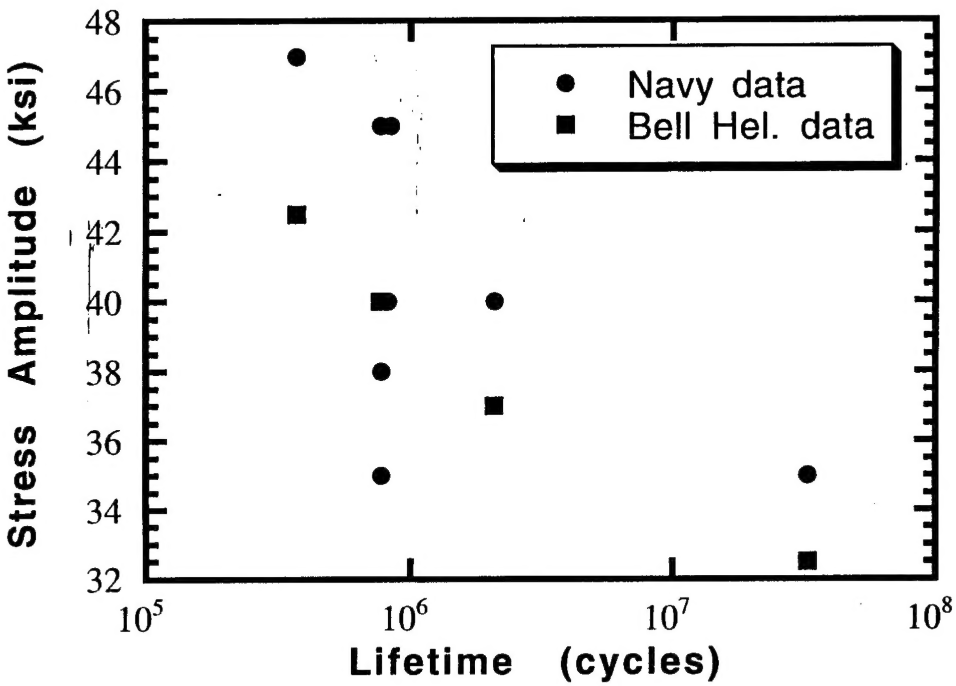
- Stress-Lifetime (S-N) Curves Plotted - Compared to Bell-Helicopter Data.

- Optical Metallography of Original Casting.

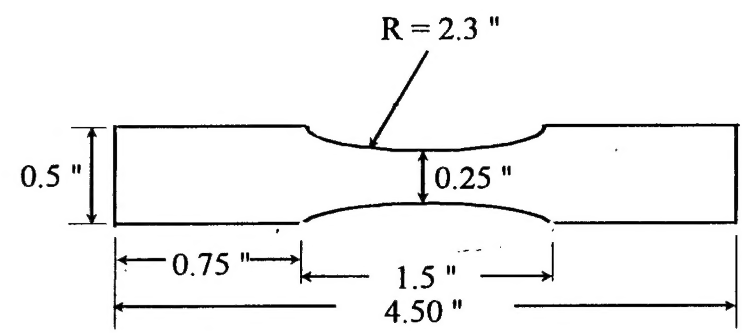
- SEM/EDS Examination of Etched Gage Surface Before Failure and Fracture Surface After Failure.

STRESS-LIFETIME (S-N) DATA

Comparison of S-N Data



Curves have to be drawn by hand.



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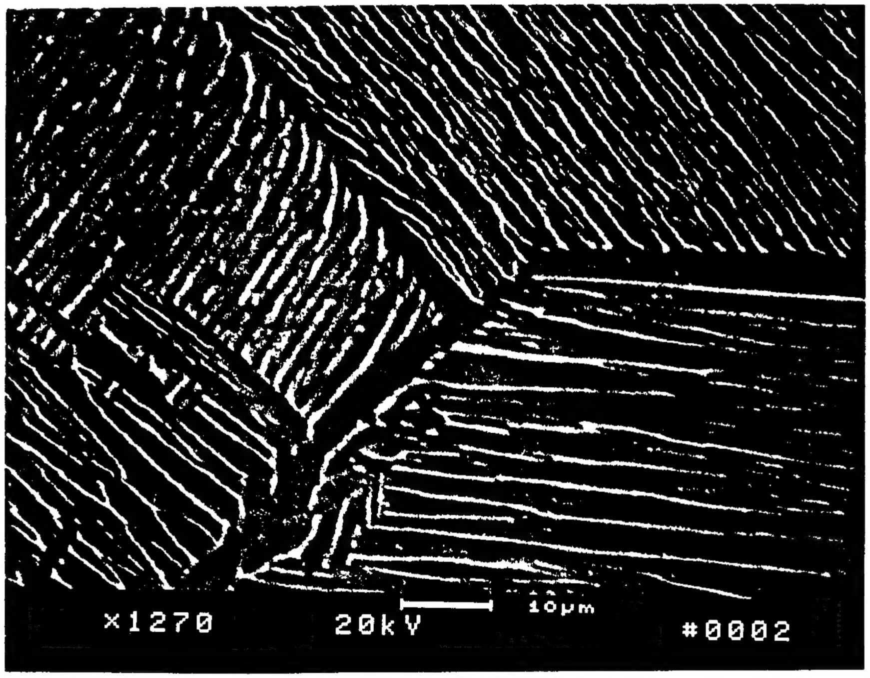
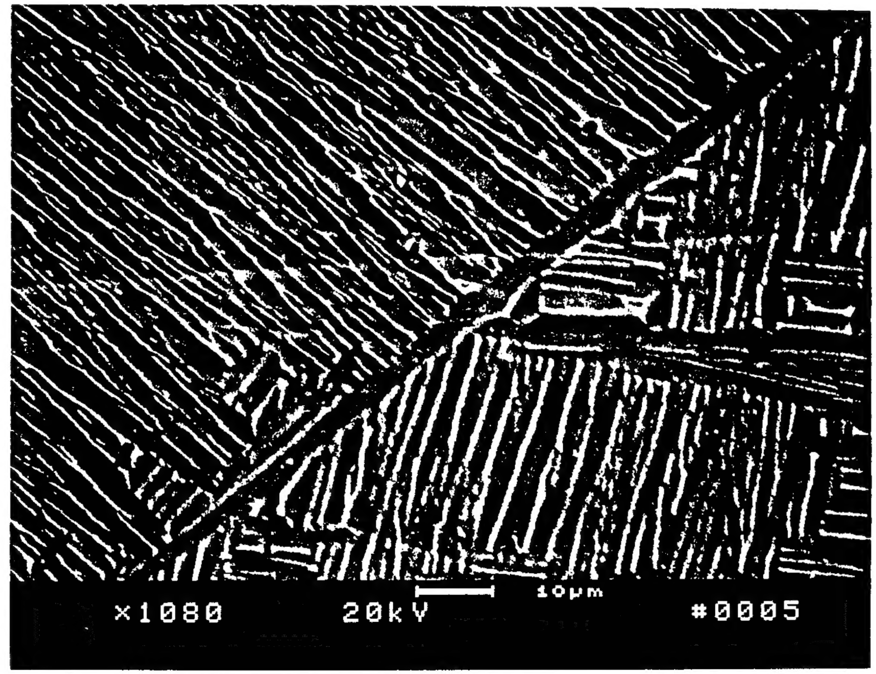
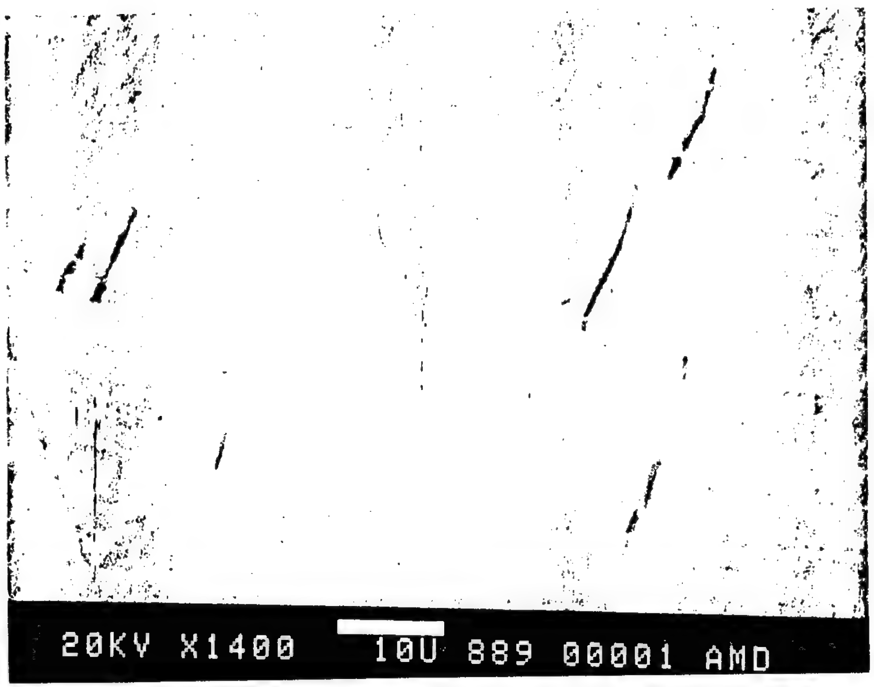
WIDMANSTATTEN MICROSTRUCTURE

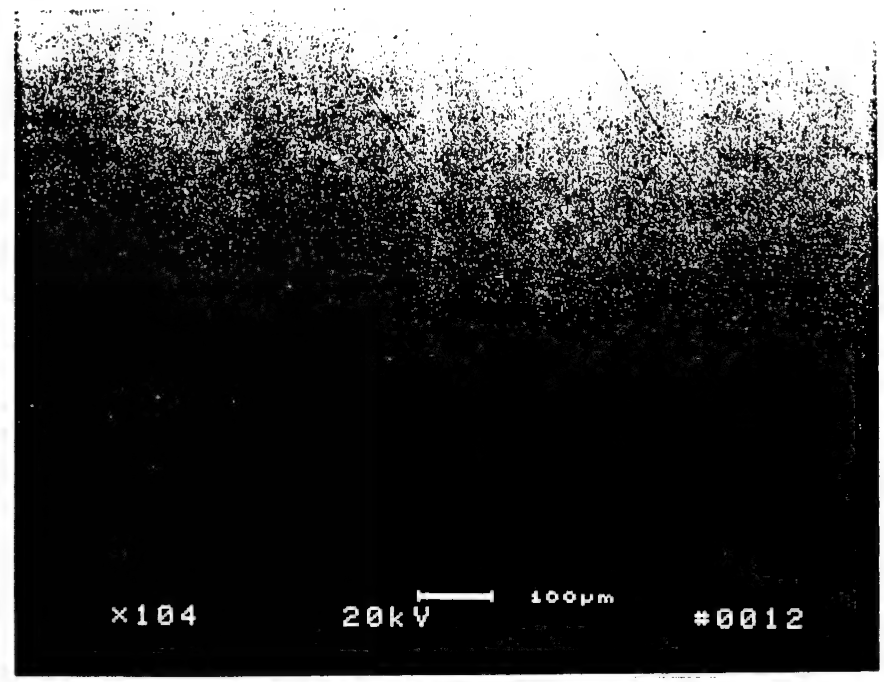




- Prior-β grain triple point visible in photo on left.
- Thicker α-platelets (~1-2 μ) separated by thin β-platelets (~0.5 μ).
- Microcrack initiating/arresting at prior-β grain boundary.

ARRAYS OF SURFACE MICROCRACKS

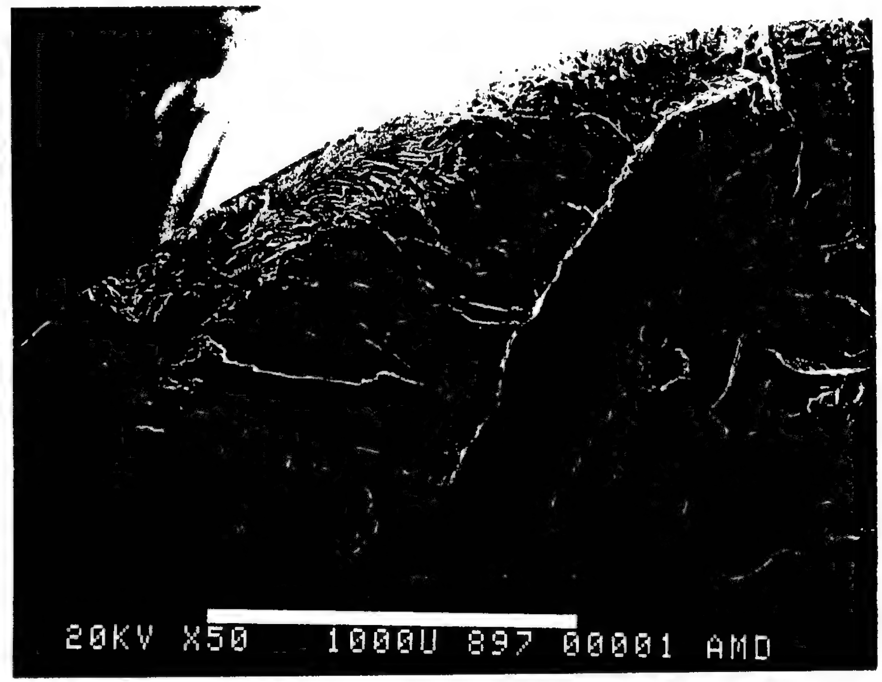




- Parallel arrays of microcracks often oriented at ~ 45° to tensile axis along a preferred crystallographic plane within a favorable grain.
- Microcracks arrest/initiate at colony and prior-β grain boundaries.

TYPICAL SHEAR INITIATION FACETS

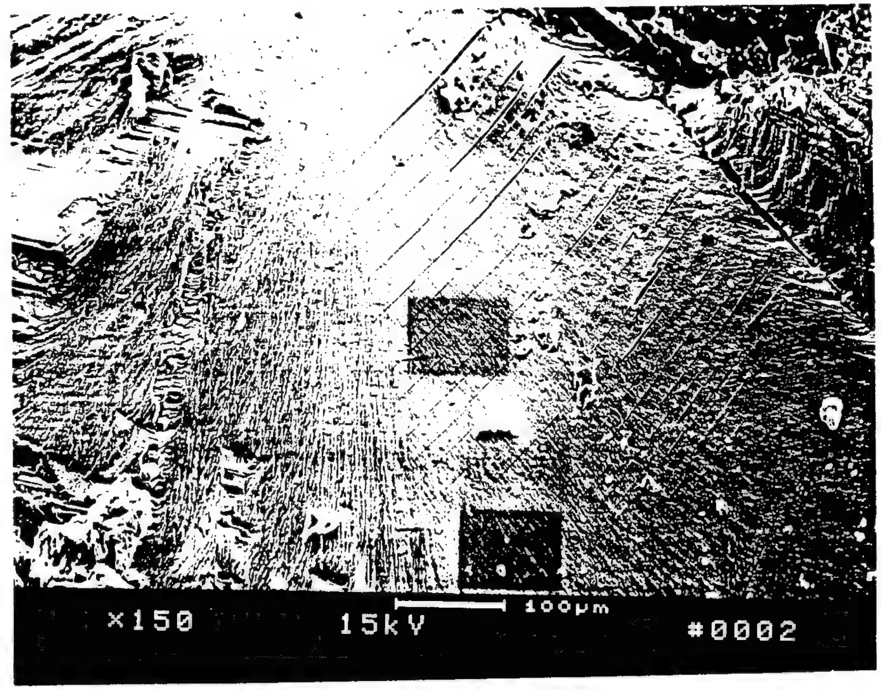
Max. dimension ~ 0.5 mm



Max. dimension ~ 1.3 mm

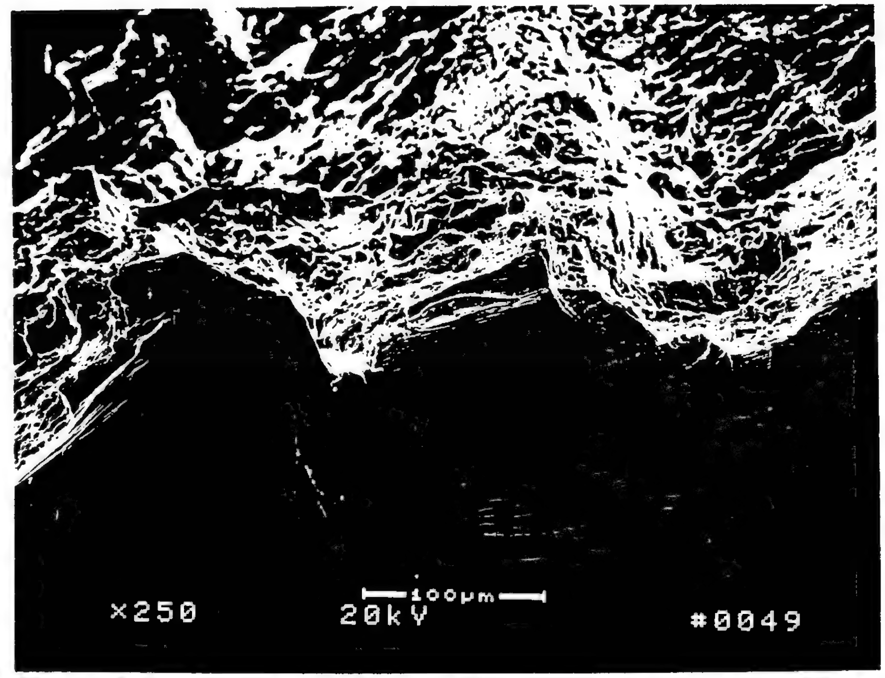
- Note flat and shiny appearance of facets.
- Grain boundary cracking often evident along boundary of facets.

MAGNIFIED VIEW OF SHEAR FACET



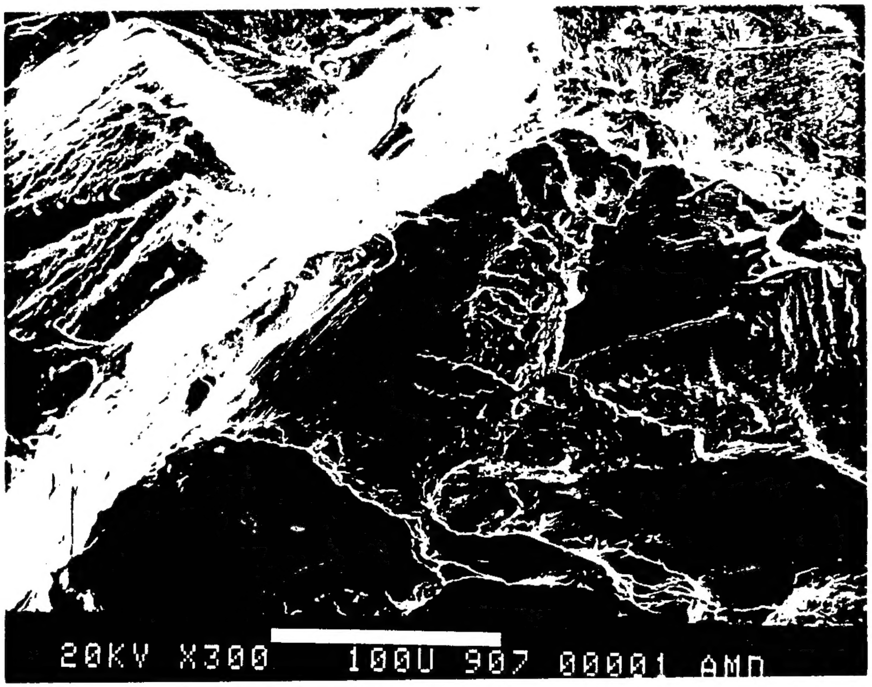
- Note regularly-spaced, extensive secondary cracking on facet.
- Prior-β grain boundary cracking also evident.
- Crack appears to radiate from a point.

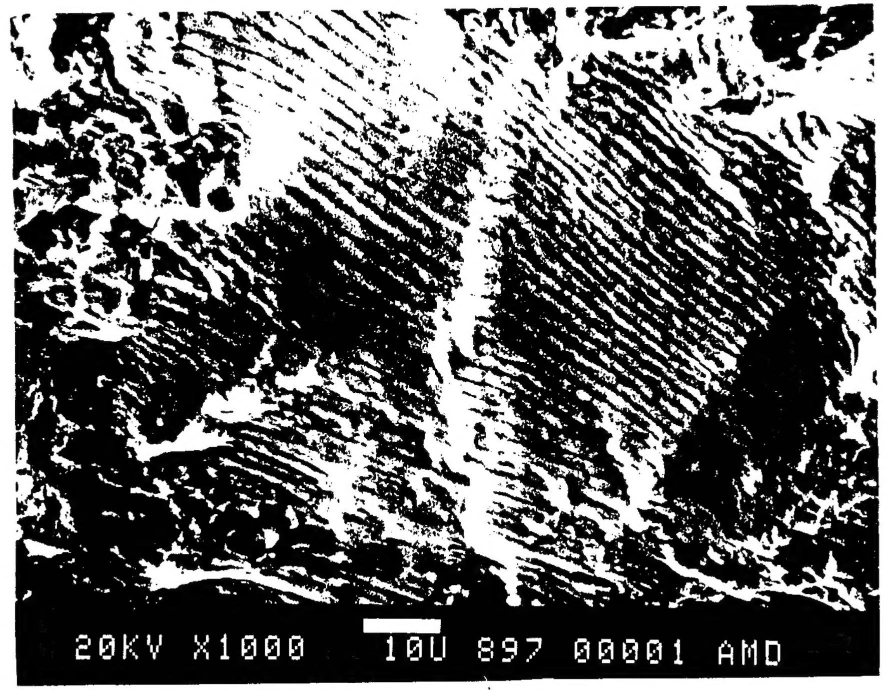
SURFACE AT FINAL FRACTURE



- Extensive deformation at surface characteristic of final fracture.
- Surface at initiation site relatively undeformed (except at very hi-mag)

STRIATED PROPAGATION





Striation density ~ 600/mm

- Just beyond initiation facet, striated propagation occurs.
- Striations are oriented differently in neighboring grains and colonies.

CONCLUSIONS

- Under high-cycle fatigue conditions, parallel arrays of microcracks form along preferred crystallographic planes in favorably oriented grains.

- Flat, shiny shear initiation facets are generally observed at or near the surface. Maximum dimension ranges from 0.5 to 2 microns which is on the order of very large colony sizes. Note that large colonies have been shown to have lower initiation resistance than small ones.

- Significant secondary cracking often observed to accompany initiation and propagation.

CONCLUSIONS (cont.)

- Prior-β grain boundary cracking often observed along boundaries of initiation facets.

- Navy S-N measurements, while showing slightly longer lifetimes, are in reasonable agreement with Bell-Helicopter data.

- While fatigue lifetimes for the cast and HIPped material are competitive with those for wrought material, significant data scatter is observed at the lower stress amplitudes. This needs to be addressed in future work.

FUTURE WORK

- Initiation crystallographic plane identification using Laue backscattered X-ray technique.

- Precise sectioning of fracture plane to determine subsurface effects on initiation (e.g., subsurface prior-β grain boundary cracking.)

- More precise measurement of initiation vs propagation times.

- Variation of casting, HIPping, and β-solution heat treatment parameters to modify microstructural features such as average colony size. Measurement of effects of these changes on fatigue behavior.